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EXPLOSIVE WIRES AS A SOURCE OF SHOCK
WAVES IN WATER

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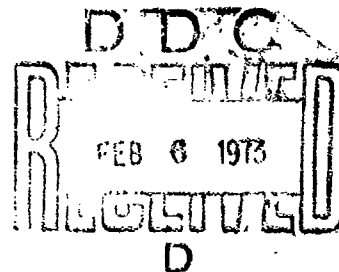
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Investigations of electrical explosion of wires (EEW) are being conducted fairly widely at the present time. Particularly many works have been devoted to EEW in air. This cannot be said of the explosion of wires in liquids. The study of the explosion of wires in condensed media, especially in water, has taken on great practical interest, in connection with the fact that EEW finds wide use as a pulse source of pressure in technological operations, for example, stamping, pipe rolling and others.

EEW in water for technological purposes possesses a number of advantages, in comparison with other pressure sources, for example, explosives, in view of the great safety of the process, the possibility of automation and so forth. Therefore, pressure in the shock wave from EEW must be studied, as a consequence of the fact that it will be determined by both the electrical circuit parameters and the material, length and cross section of the wire. Pressure pulses in the shock wave, vs. the generator and exploding wire parameters, have been inadequately studied, although there are works devoted to EEW in water [1,2].

The electrical explosion of wires in various circuit parameters are investigated in [3]. The action of the explosion is evaluated by the magnitude of caving in of a free metallic diaphragm, placed next to the exploding wire. Proceeding from the optimum wire resistance conditions (by optimum resistance

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the authors understand resistance of a wire $R_w = 1.2 \sqrt{L/C}$ at the moment of its explosion), its optimum length and cross section are found:

$$S_{opt} = K_1 CU\ f^{2/3}, l_{opt} = K_2 U\ f^{-2/3}, \qquad (1)$$

where C is the circuit capacitance , U is the voltage, f is the circuit frequency and K_1 and K_2 are coefficients which depend on the wire and medium material.

It was shown in [3] that the greatest deformation of the diaphragm is observed at maximum output, corresponding to an explosion of the wire at the maximum current pulse. The formulas presented do not connect pressure on the shock wave front with generator and wire parameters. The method of measuring diaphragm deformation for evaluation of pressure in an explosion is applicable only in conduct of comparative tests [4]. Therefore, there is interest in finding S_{opt} and l_{opt} experimentally, using a different method of measurement of pressure on the shock wave front, and in verifying the applicability of the values obtained for coefficients K_1 and K_2 to different test conditions.

The results of study of wire explosion conditions for obtaining the maximum values of the shock wave pressure amplitude, with various generator and wire parameters, are set forth in this work. A current pulse generator, composed of type IM-50/3 condensers, with a total discharge capacity of 20 µfarad, was used in the experiments. The discharge voltage changed from 7 to 20 kv. The wire being studied and pressure sensors were placed in a metal container, measuring 750 x 750 x 1200 mm^3. The oscillograph circuit for display of current, voltage and synchronization is analogous to that described in [5]. Pressure in the shock wave front in water was measured by a pulse pressure sensor [6], which was sealed in epoxide resin to insure airtightness. Dimensions of the $BaTiO_3$ pellet were 8mm in diameter and 4mm thick. The signal from the sensor, adjusted by a cathode follower, with an output link to a OK-17M oscillograph, moved a plate, clearing the amplifier circuit. The distance R from the exploding wire axis to the sensor varied within the limits of 150-200 mm. Start-up of the oscillograph for recording pressure was accomplished by a similar pressure sensor. Calibration of the sensor was carried out by the method of [4], and the results of [7] were used for calculating the pressure field.

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The experiments were conducted with copper and constantan wires, for study of the effect of EEW material on shock wave pressure amplitude in water. The wires differed considerably in resistivity ρ and sublimation energies. It was shown earlier [8] that the shock wave speed is greater from an exploding wire in air with a smaller ρ, under otherwise identical test conditions.

A comparison of the energetic and hydrodynamic characteristics of exploding wires of various materials can be made only for the optimum wire explosion conditions. Conditions providing the maximum value of shock wave pressure amplitude are understood by this. The relationship of pressure to wire length (copper and constantan) of various cross sections, with identical generator energy, was studied for determination of the optimum conditions. It is apparent from the relationship of pressure of the shock wave front to wire length obtained [Fig. 1] that pressure is 1.2 times greater for copper, with optimum copper and constantan wire cross sections and identical generator energy values. This fact is demonstrated by a comparison of the current oscillograms. Thus, in the case of copper wire, the current value I_{max} at the moment of the explosion and the energy accumulated in the magnetic field $LI^2_{max}/2$ is greater than in the explosion of a constantan wire. Here, the magnetic field energy, being converted into electrical, is discharged into the wire material, causing additional heating of it. The great energy introduced into the copper wire in a shorter time, under otherwise equal conditions, can only lead to increase in pressure in the shock wave front, which is confirmed by experiment.

Shock wave pressure vs. length of copper wire, for three generator voltage values, are presented in Fig. 2. The optimum value of the wire cross section was found first for each wire, just as was done in Fig. 1. It is apparent that pressure is proportional to voltage, at constant generator capacitance. The function $P = f(S)$, presented in Fig. 3, was studied, in order to establish the connection between pressure in the shock wave front and cross section of a wire of optimum length. As is apparent, the optimum value of the wire cross section is connected linearly with voltage at one and the same circuit frequency.
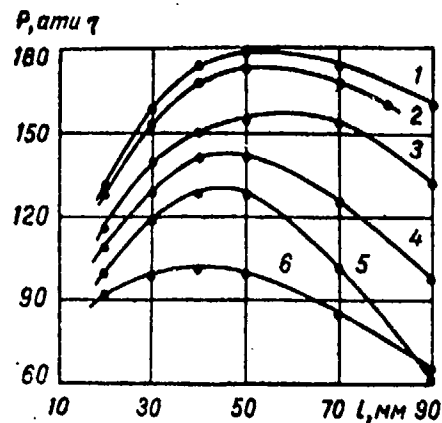
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Fig. 1.   Function P = f (1) for 343 Joule Generator Energy;
Distance to the Sensor 150 mm, Wire Material, Copper (Curves
1-3) and Constantan (Curves 4-6):   1.   d = 0.27 mm; 2. 0.23 mm;
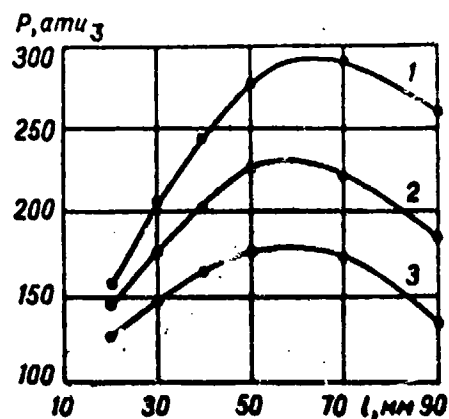3. 0.31 mm;   4. 0.30 mm; 5. 0.40 mm;6. 0.20 mm; 7. Pressure,
P, atm.

Fig. 2.   Function P = f (1) for Three Voltage Values;
Capacitance 14 μFarad, Distance to Sensor 150 mm; Wire
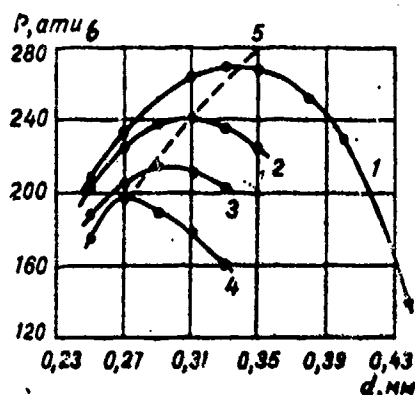Material, Copper: 1. d = 0.31 mm, U = 9 kv; 2. 0.27 mm, 7 kv;
3. Pressure, P, atm.

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Fig. 3. Function P = f (S) for Various Generator Energy
Values; Capacitance 20 μFarad; Distance from Wire Axis to
Sensor, 200 mm; Wire Material, Copper: 1. U = 10 kv; 2. 9 kv;
3. 8 kv; 4. 7 kv; 5. [Pressure maxima]; 6. Pressure, P, atm.

The results obtained by determination of S_{opt} and l_{opt} with
piezoelectric pulse pressure sensors were compared with data
calculated by formulas [1]. The results of this comparison
are presented in the table. Satisfactory matching of calculated
and experimental data, for optimum wire cross sections and
lengths, over the entire range of their measurements studied,
are evident from the table. The divergences are within the
limits of error of the experiment.

CONCLUSIONS

1. Pressure in the shock wave front, in an explosion of
wire in water, in relation to generator and wire parameters,
was studied.

2. It was demonstrated that wires with a large sublimation
energy and smaller ρ must be used to obtain the maximum pressure
on the shock wave front.

3. Optimum values of length and cross section of wires
exploding in water were determined. They coincide with those
calculated by formulas [1,2], within the actual limits of change
of generator and exploding wire parameters investigated by us.

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f, кгц 1	L, мкгн 2	C, мкф 3	U, кв 4	$W_{зап}$, дж 5	$d_{эксп}$, мм 6	Данные 7			
						экспериментальные 8		расчетные 9	
						S, мм²	l, мм	S, мм²	l, мм
15,6	5,32	19,6	7 8 9 10	490 627 794 980	0,27 0,29 0,31 0,35	0,0573 0,0660 0,0755 0,0962	50 60 60 —	0,0613 0,0700 0,0780 0,0880	48,5 55,4 62,2 69,1
20,4	4,35	14	7 9 11	343 567 847	0,27 0,31 0,35	0,0573 0,0755· 0,0962	50 60 50	0,0527 0,0676 0,0829	40,4 51,8 63,4
23,5	3,92	11,74	9 11,5	476 775	0,25 0,31	0,0491 0,0755	40 50	0,0624 0,0796	47,2 60,4
28,4	3,56	8,83	10 13,5	441 805	0,25 0,27	0,0491 0,0573	40 50	0,0591 0,0697	46,2 62,3
37,6	3,05	5,88	13 16	496 754	0,27 0,31	0,0573 0,0755	40 60	0,0610 0,0753	50 61,3
58,6	2,54	2,89	18	470	0,25	0,0491	50	0,0565	51,1

1. Frequency, f , khz. 2. Inductance, L, μ henry. 3. Capacitance, C, μfarad. 4. Voltage, U, kv. 5. Accumulated Energy, W_{ac}, joule. 6. Distance, d_{exper}, mm. 7. Data.

8. Experimental. 9. Calculated.

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